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Effects of irrigation frequency on growth and yields of *Taraxacum kok-saghyz* Rodin

Guang Shen[1], Fuyun Zheng[1], Lin Zhou[1], Xiangjun Zeng[2], Nina G. Konkova[3]

[1] *Institute of Natural Resources and Ecology, Heilongjiang Academy of Sciences, Harbin, China*

[2] *Heilongjiang Academy of Sciences, Harbin, China*

[3] *N.I. Vavilov All-Russian Institute of Plant Genetic Resources, St. Petersburg, Russia*

Corresponding author: Guang Shen, shen19772@163.com

Taraxacum kok-saghyz (TKS) is one of the most promising rubber plants in the world. The question of how irrigation affects its yields and biochemical composition has not yet been studied well. The effects of irrigation frequency on the growth and yield of *Taraxacum kok-saghyz* were analyzed. According to the obtained results, it was established that an increase in irrigation frequency (extension of the watering interval) gradually decreased TKS rubber and total sugar yields. With the soil water content increasing from 22.8 to 38.9%, TKS rubber and sugar yields were changing in line with a cubic polynomial equation. Regular watering once every 6 days maintains soil moisture at a level above 28.0%, which makes it possible to increase the yield of *Taraxacum kok-saghyz* while enhancing the water-use efficiency under the conditions of Northeastern China (Harbin).

Keywords: *Taraxacum kok-saghyz*, irrigation frequency, leaf biomass, rubber content, sugar content

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ИЗУЧЕНИЕ И ИСПОЛЬЗОВАНИЕ ГЕНЕТИЧЕСКИХ РЕСУРСОВ РАСТЕНИЙ

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Влияние частоты полива на рост и урожайность *Taraxacum kok-saghyz* Rodin

Г. Шень[1], Ф. Чжэн[1], Л. Чжоу[1], С. Цзэн[2], Н. Г. Конькова[3]

[1] Институт природных ресурсов и экологии Академии наук провинции Хэйлунцзян, Харбин, Китай

[2] Академия наук провинции Хэйлунцзян, Харбин, Китай

[3] Федеральный исследовательский центр Всероссийский институт генетических ресурсов растений имени Н.И. Вавилова, Санкт-Петербург, Россия

Автор, ответственный за переписку: Гуан Шень, shen19772@163.com

Taraxacum kok-saghyz – одно из самых перспективных каучуконосных растений. Недостаточно изучено влияние полива на урожайность и биохимический состав кок-сагыза. В исследовании изучалось влияние частоты полива на рост и урожайность *Taraxacum kok-saghyz*. Согласно полученным результатам было установлено, что увеличение частоты полива (увеличение интервала полива) постепенно снижало содержание каучука и общий выход сахара у кок-сагыза. С увеличением содержания воды в почве с 22,8 до 38,9% выход каучука и сахара существенно менялся в соответствии с кубической зависимостью (уравнением кубического полинома). Регулярный полив один раз в 6 дней поддерживает влажность почвы на уровне 28%, что позволяет увеличить урожайность кок-сагыза при одновременном повышении эффективности водопользования в условиях северо-восточного Китая (Харбин).

Ключевые слова: *Taraxacum kok-saghyz*, частота полива, биомасса листьев, содержание каучука, содержание сахара

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Introduction

Taraxacum kok-saghyz Rodin (TKS) is a perennial plant which adapts to mid-temperate continental monsoon climate and moderately cold climatic zones. Its root contains 2.89–27.89% of rubber (Cornish, 2017; Taiz et al., 2015) and 25–40% of inulin (Oki, Kanae, 2006). It is one of the most promising rubber plants in the world (Cornish, 2017). TKS leaves have high antioxidant capacity because of their significant content of phenolic compounds, including flavonoid and tannin content (Vörösmarty et al., 2000). Because of its short growth cycle, TKS can be a natural model for studying the mechanism of rubber accumulation (Sinclair et al., 1984). Therefore, TKS is a multi-application plant with important economic and scientific values.

Water is the most important factor affecting plant growth and yield of agricultural crops (Taiz et al., 2015). The growth of the human population, environmental pollution, and climate change are making water resources more and more scarce (Oki, Kanae, 2006; Vörösmarty et al., 2000) for many countries, especially for the developing ones, so the enhancement of water-use efficiency is one of the most important scientific tasks (Sinclair et al., 1984).

One of the urgent modern trends in science is the investigation of the influence of various irrigation schemes on the growth, development and yield of rubber plants. Although *Hevea brasiliensis* is the main source of natural rubber, the effects of different watering schemes on its development are less studied (Carr, 2012). For example, increasing the frequency of irrigation increases the gain of aboveground biomass of *Hevea brasiliensis* (Devakumar et al., 1999), but excessive water can hinder development and cause the root rot (Gomes, Kozlowski, 1988). Investigations into the influence of draught stress and different irrigation schemes on the guayule (*Parthenium argentatum* L.) growth confirm that an increase in irrigation frequency accelerates the development of *Parthenium hysterophorus* aboveground and belowground biomass, and increases the rubber yield (Nakayama et al., 1991; Miyamoto, Bucks, 1985; Veatch-Blohm et al., 2006). Some studies estimated the ratio of guayule harvest to water consumption (Bucks et al., 1985; Fangmeier et al., 1950) to provide theoretical guidelines for crop production. Before the 1960s, the research on water impact on TKS development was mainly concentrated on the effects of climate, soil environment, and irrigation methods. The current study indicated that irrigation frequency affected rubber content, but not inulin, biomass, and other morphological characteristics (Arias et al., 2016).

The aim of this study was to provide theoretical support for the development of new TKS irrigation technologies:

1) determination of the minimum water amount that is necessary to maintain a high TKS yield, and

2) assessment of the effect of irrigation frequency on TKS yield parameters.

Experimental design and methods

Study site

The experiment was carried out at the Institute of Natural Resources and Ecology, Heilongjiang Academy, in Harbin (E 126°38’45.5”, N 45°42’45.4”) in 2015. Harbin region has a mid-temperate continental monsoon climate with a mean annual temperature of 4.2°C, annual precipitation of 569 mm, and frost-free period of 145 days.

The cultivation soil type is black soil with the following physical and chemical properties: organic carbon = 62.3 g kg^{-1}; alkali-hydrolysable nitrogen = 223.0; available phosphorus = 156.3; available potassium = 552.0 mg kg^{-1}; bulk density = 1.68 g m^{-3}.

Plant materials

All plant materials were obtained from accession k-445 provided by the N.I. Vavilov Institute of Plant Genetic Resources (VIR), Russia, in 2012. After 2 years of domestication and cultivation in Harbin for complete adaptation to the local soil and climate environment of Harbin region, the seeds were harvested and stored at 4°C after cleaning in 2014. During the experiment, the seedlings were raised in the greenhouse in mid-April (16–22°C), and seeds were planted in the field on July 1 (2 months after germination, at the stage of 5–7 leaves).

Experimental design

This study was carried out according to a potted single-factor randomized block experimental design.

In early July 2015, in a ventilated plastic shed, 2-month-old TKS seedlings were transplanted into pots (upper diameter = 20.7 cm; lower diameter = 14.5 cm; height = 17.8 cm; volume = 3.1 L), with sufficient watering. After 1 month of normal growth management, the main irrigation frequency experiment was carried out.

The experiment included four irrigation frequency gradients with watering once every 12, 9, 6, and 3 days (treatments Nos. 1, 2, 3, and 4, respectively), 400 mL of water was added to each plant for the proper water soil saturation. Each treatment had 3 replications, with 10 TKS plants per replication, 120 plants in total (Fig. 1).

Research methods

During the experiment, soil water content and plant growth parameters were dynamically monitored. After the aboveground part withered in early November, the underground part was taken out of the pot, and other indicators were measured after cleaning.

Monitoring of soil water content: after treatment 1 was fully watered, 5 soil samples were randomly taken every day, and the corresponding soil water content was measured by the weighing method for 12 consecutive days.

Monitoring of plant growth status: measuring the crown width and number of leaves of each plant every 20 days (August 6, August 24, September 6, and September 24, respectively).

Other indicators:

After the rhizomes of TKS were taken out of the pot and cleaned, the stem diameter, root length, root number, underground biomass, rubber content, total sugar and reducing sugar content for each TKS plant were measured, and water-use efficiency of each treatment was calculated.

Water-use efficiency (WUE) = underground dry matter (B) / water consumed (WU) (Sinclair et al., 1984).

Soil organic carbon content was determined by the potassium dichromate–external heating method, total nitrogen by the Kjeldahl method, available nitrogen by the indophenol blue colorimetric method, total phosphorus by the molybdenum antimony anti-colorimetric method, total potassium by the sodium hydroxide melting method, available potassium by the sodium acetate extraction method, available phosphorus by the sodium bicarbonate method, and bulk density the by ring knife method (Ehrler et al., 1985; Hunsaker, Elshikha, 2017).

Data processing and analysis

All measured data were input into Excel, and then R language (R Core Team, 2020) was used to clean the data in the

Fig. 1. ***Taraxacum kok-saghyz*** **Rodin (TKS) plants included in the irrigation frequency experiment. Greenhouse stage**

Рис. 1. **Растения *Taraxacum kok-saghyz* Rodin (TKS), включенные в эксперимент по частоте полива. Тепличный этап**

R Studio (R Studio Team, 2015) environment, and the missing values and outliers were removed. In order to test the trend of the influence of irrigation frequency on TKS yield and its constituent factors within the variation range of each index value, we used the trend analysis method to test whether the change trend conformed to a linear, quadratic, or cubic equation. Based on the *P* value and variance weight (η^2), we determined which model is more suitable. The specific calculation method refers to the work by Roger E. Kirk (Kirk, 2013). Since the trend analysis is to carry out the variance analysis within the numerical variation range of the current measurement index, the fitted equation model is only applicable to the current numerical range. The variance analysis was performed using the aov() function in the R language, and ggplot2 (Wickham, 2016) was used in combination with the patchwork software package for plotting.

Results and analysis

Changes in soil water content

The soil water content began to decrease rapidly, the decreasing slowed down only after the 8th day after irrigation.

On the 1st day after watering the soil moisture content was 38.9%, on the 4th day it decreased to 34.5%, on the 7th day to 28.0% (treatment 4), on the 10th day to 24.5% (treatment 3), on the 13th day to 22.8% (treatment 2) and to 22.8% (treatment 1) (Fig. 2).

Impact of irrigation frequency on the parameters of TKS aboveground parts

At the early stage of growth, the TKS leaf rosette diameter at treatment 4 was the largest and appeared significantly larger than that at treatment 1, followed by treatment 2, and treatment 3. As the growth continued, the difference between treatment 4 and treatment 3 was not significant ($P > 0.05$), these parameters were significantly larger compared with the other numbers of treatments.

The final leaf rosette parameters at all treatments reached 20.8–30.3 cm, increasing 1.2–1.7 times compared to the initial growth stage, while the maximum value was approximately 1.4 times higher than the minimum (Fig. 3).

In the early stage of growth, leaf biomass at treatment 4 was the largest, being significantly larger than that at other treatments. The differences between parameters of treat-

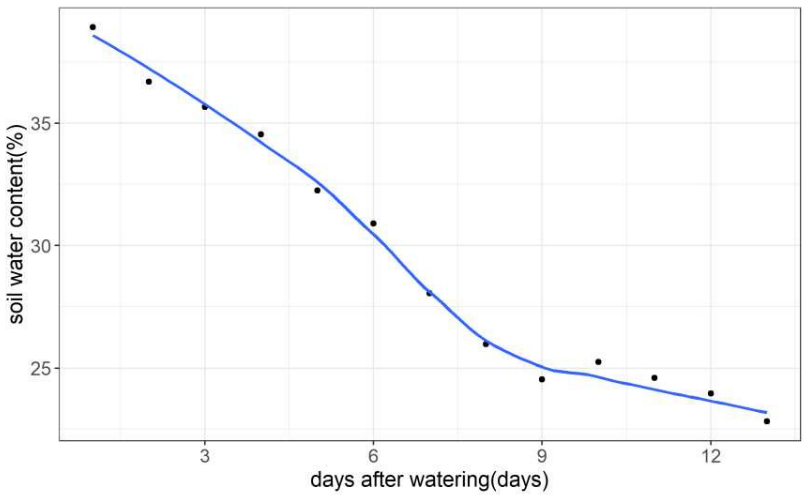

Fig. 2. **Dynamics of changes in soil water concentration over 12 days**

Рис. 2. **Динамика изменения концентрации воды в почве за 12 дней**

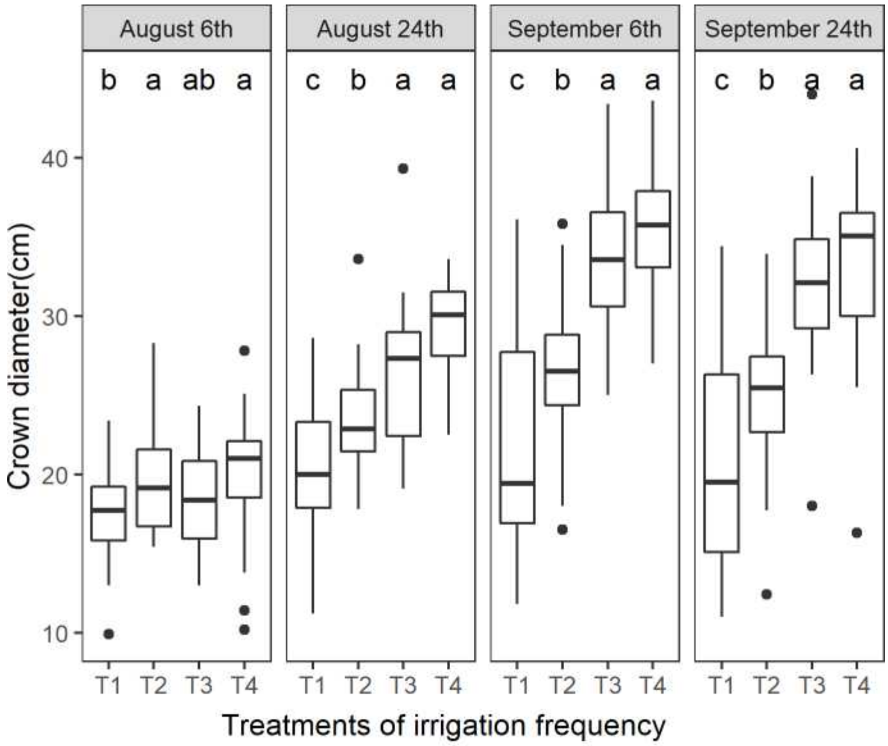

Fig. 3. **Dynamics of *Taraxacum kok-saghyz* Rodin (TKS) crown diameter alterations with the changing irrigation frequency**

Рис. 3. **Динамика изменения диаметра розетки *Taraxacum kok-saghyz* Rodin (TKS) при изменении частоты полива**

ments 2 and 3 were not significant, and the parameter of treatment 1 was the smallest, significantly smaller than at other treatments. As the growth continued, the differences between the treatments' parameters gradually increased. At the final stage of development, the differences between the parameters of each treatment were statistically significant.

The maximum value of 104.1 g/plant corresponded to treatment 4, being more than 5 times larger than that at treatment 1, so the value increased 1.6 to 5.3 times compared with the initial growth stage (Fig. 4).

Impacts of irrigation frequency on the parameters of TKS belowground parts

There was no significant difference in the stem diameter between treatments 3 and 4: 19.5 and 20.7 cm, respectively. But their parameters were significantly larger than those of treatments 1 and 2. Meanings of treatment 2 (13.6 cm) were significantly larger than those of treatment 1. The maximum value was 1.5 times larger than the minimum (Fig. 5, A). There was no significant difference in the root number among the treatments, ranging from 5.1 to 6.3 (Fig. 5, B). The difference in root length between treatments 3 and 4 was not significant (about 32 cm); both parameters were significantly larger than at treatments 1 and 2. TKS root length at treatment 1 was significantly smaller (24.6 cm) compared with other treatments. The difference between the maximum and minimum values was about 1.3 times (Fig. 5, C). The distinction in belowground biomass parameters between treatment 3 and 4 was not significant (10.6 and 11.0 g/plant). Both values were significantly larger than those at treatment 1 and treatment 2. The parameters at treatment 2 (4.1 g/plant) were significantly larger than at treatment 1. The difference between the maximum and minimum values was about 2.6 times (Fig. 5, D).

Rubber content at treatment 1 was the smallest (4.78%), being significantly lower than that at other treatments. The differences in rubber content between other treatments were not significant, and the maximum value was 5.13% (Fig. 6, A).

Total sugar values at all treatments ranged from 41.0 to 50.8%. (Fig. 6, B). The difference in the total sugar yield at treatments 3 and 4 was significantly greater than that at treatment 1 and 2. The total sugar yield at treatment 2 (41.0%) was significantly higher compared with treatment 1. The maximum value was about 1.2 times larger than the minimum value (Fig. 6, C). The rubber yields at treatments 3 and 4 (539 and 564 g/plant, respectively) were significantly higher than those at treatment 1 and treatment 2. The value of treatment 1 (198 g/plant) was significantly lower compared with other treatments. The maximum value was about 2.8 times higher than the minimum (Fig. 6, D).

Impact of irrigation frequency on the root/leaf ratio

The root/leaf ratio of TKS obviously decreased with the increasing irrigation frequency. Higher moisture content in the soil corresponded to a lower ratio of roots to leaves, from 1.85 (treatment 1) to 0.85 (treatment 4) (Fig. 7).

Trend analysis of the irrigation frequency effect on TKS yield parameters

The increase in soil moisture (irrigation frequency indicator) from 22.8 to 38.9% caused an increase in TCS leaf biomass from 19.5 to 104.1 g/plant. This trend was significantly in line with linear, quadratic, and cubic trends, but mostly fitted the cubic polynomial model, $\eta^2 = 0.579$, $P < 0.001$ (Fig. 8, A). The root biomass of TKS increased from 4.1 to 11 g/plant. The change trend was significantly in line with the quadratic and cubic models, but the cubic polynomial model was the best suitable, $\eta^2 = 0.531$, $P < 0.001$ (Fig. 8, B). There was no obvious trend in the TKS rubber and total sugar con-

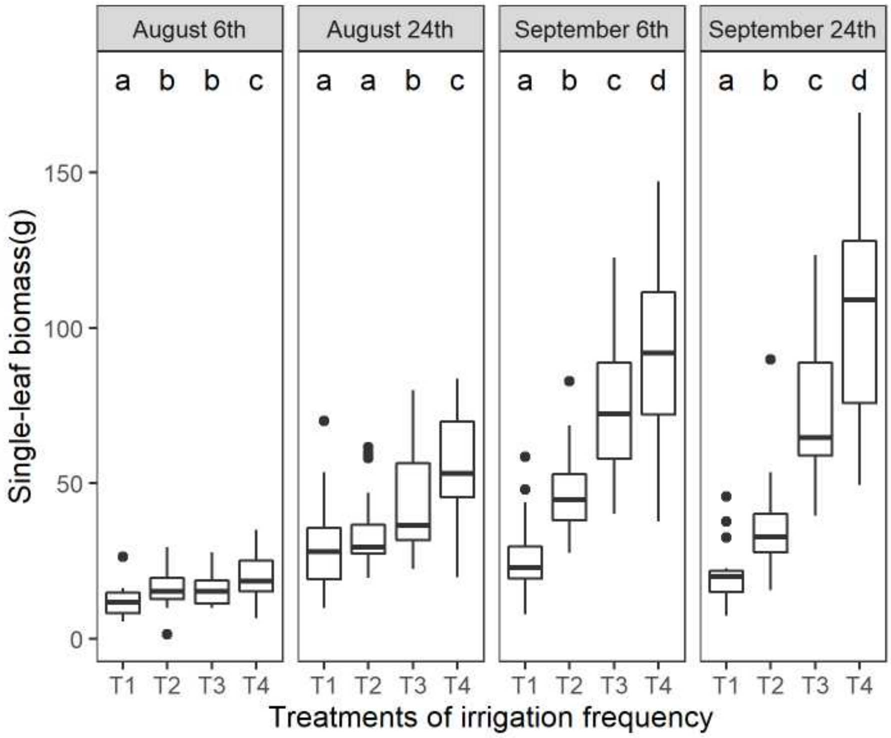

Fig. 4. **Dynamics of *Taraxacum kok-saghyz* Rodin (TKS) leaf biomass alterations with the changing irrigation frequency**

Рис. 4. **Динамика изменения биомассы листьев *Taraxacum kok-saghyz* Rodin (TKS) при изменении частоты полива**

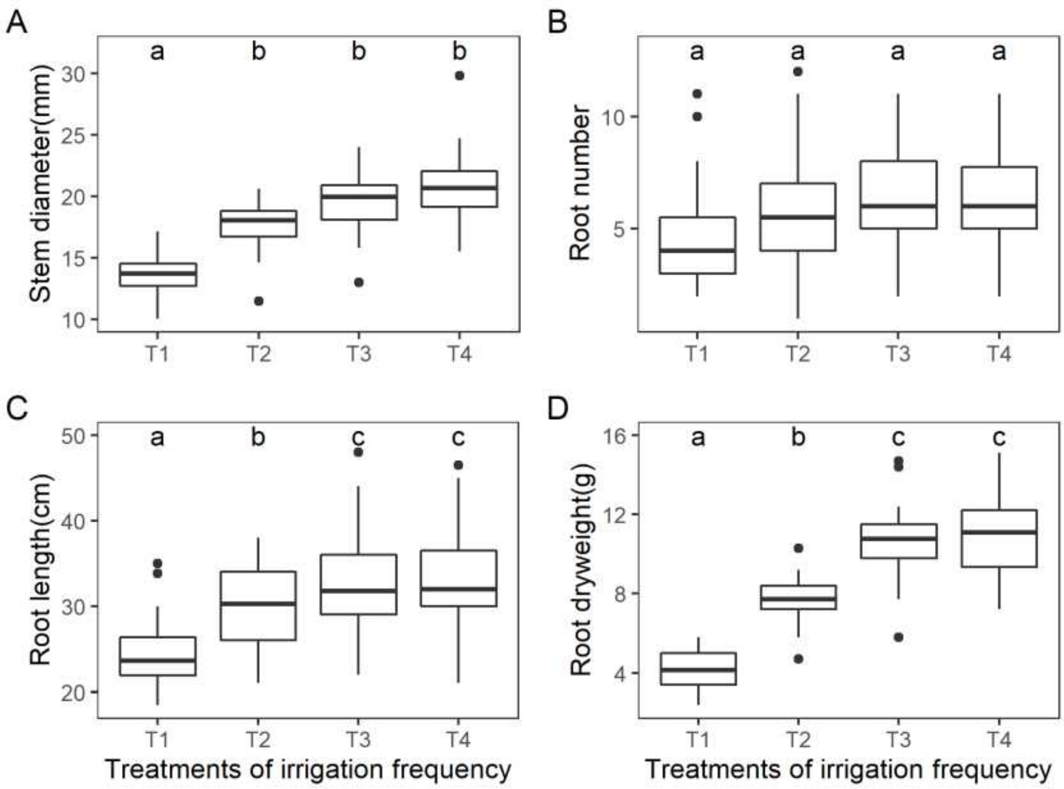

Fig. 5. **Dynamics of *Taraxacum kok-saghyz* Rodin (TKS) root trait alterations with the changing irrigation frequency**

Рис. 5. **Динамика изменения признаков корней *Taraxacum kok-saghyz* Rodin (TKS) при изменении частоты полива**

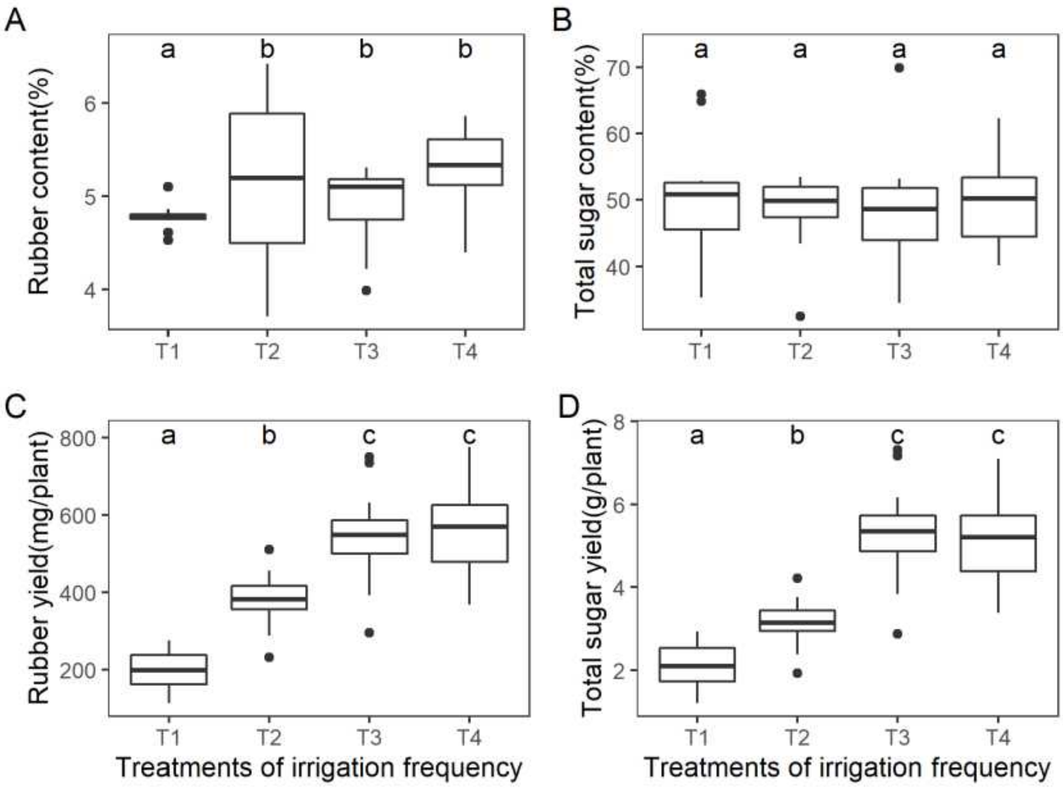

Fig. 6. **Dynamics of *Taraxacum kok-saghyz* Rodin (TKS) rubber and sugar yield alterations with the changing irrigation frequency**

Рис. 6. **Динамика изменения выхода каучука и сахара *Taraxacum kok-saghyz* Rodin (TKS) при изменении частоты полива**

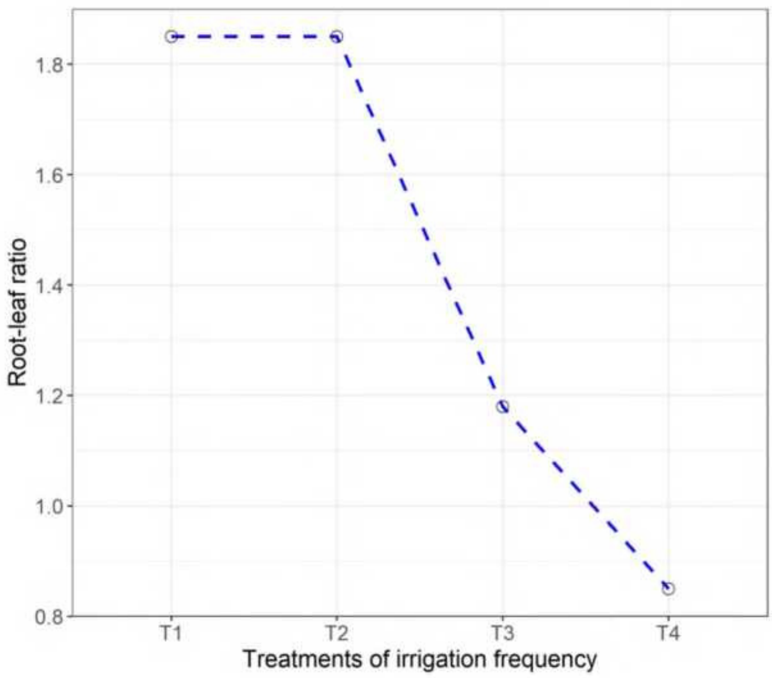

Fig. 7. **Impact of irrigation frequency on the *Taraxacum kok-saghyz* Rodin (TKS) root/leaf ratio**

Рис. 7. **Влияние частоты полива на соотношение корни/листья *Taraxacum kok-saghyz* Rodin (TKS)**

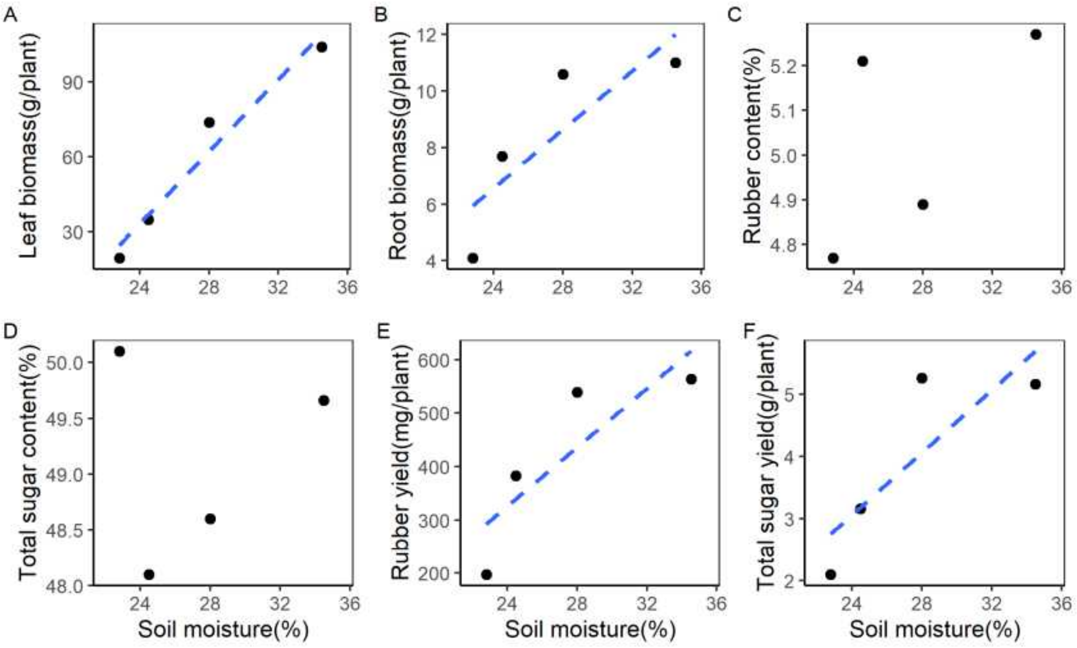

Fig. 8. **Curves of the irrigation frequency impact on leaf and root biomass, rubber and sugar content, rubber and sugar yield in *Taraxacum kok-saghyz* Rodin (TKS)**

Рис. 8. **Кривые влияния частоты полива на биомассу листьев и корней, содержание каучука и сахара, выхода каучука и сахара у *Taraxacum kok-saghyz* Rodin (TKS)**

tent changes (Fig. 8, C, D). TKS rubber yield increased from 197.6 to 563.6 g/plant. The change trend was significantly in line with the quadratic and cubic models, but the cubic polynomial model was most suitable, $\eta^2 = 0.550$, $P < 0.001$ (Fig. 8, E). The change trend of the total sugar yield from 100.4 to 264.9 g/plant was significantly in line with linear, quadratic, and cubic trends, but the cubic polynomial model was the best fitted, $\eta^2 = 0.463$, $P < 0.001$ (Fig. 8, F).

Water-use efficiency

Treatment 2 had the highest water-use efficiency (193 g m^{-3}), followed by treatment 3 (177 g m^{-3}) and treatment 1 (144 g m^{-3}). Treatment 4 had the lowest water-use efficiency (92 g m^{-3}) (Table 1). It means that under pot conditions, watering every 9 days was the most efficient.

Discussion

Overall, with the reduction in irrigation frequency or soil water content, the crown diameter, leaf biomass, stem diameter, root length, root biomass, rubber yield, and total sugar yield of TKS gradually decreased except for the parameters of root number and total sugar content.

Since the difference in rubber yield and total sugar yield was consistent with the difference in rhizome biomass, it can be concluded that the frequency of irrigation mainly affects the yield through a change in the parameters of the TKS root biomass.

The study indicated that the TKS rubber and total sugar yield were maximum at treatments 3 and 4 (watering every 6 and 3 days, respectively). On the other hand, less water was

Table 1. **The effect of irrigation frequency on water-use efficiency**

Таблица 1. **Влияние частоты полива на эффективность водопользования**

Treatments	Belowground dry weight (g)	Rubber yield (g)	Amount of water (m^3)	Water-use efficiency of biomass (g-m'3)	Water-use efficiency of rubber yield (g < 3)
T1	4.1	0.198	0.028	144	7.1
T2	7.7	0.383	0.04	193	9.6
T3	10.6	0.539	0.06	177	9.0
T4	11.0	0.564	0.12	92	4.7

used in treatment 3, hence the water-use efficiency was higher. Although the water-use efficiency at treatment 2 was higher, the yield was significantly lower compared to treatment 3. Therefore, the 3rd treatment option (watering once every 6 days) was the most efficient for water use and for the achievement of the best TCS yields.

By monitoring soil moisture, we found that the indicator began to show a significant downward trend on the 6th day after watering, at that time when the soil moisture was 28.0%. The water supplementation carried out at treatment 3 indicated that the amount of soil moisture equal to 28.0% was critical for the TKS development. Therefore, it is necessary to control the soil water content and keep it above 28.0%, which ensures normal growth and high rubber yields.

Sugars are the plant's reserve compounds and play the role of activity regulators for many genes (Halford et al., 2011). Water stress can affect physiological and biochemical processes in plants (Hsiao et al., 1976; Hanson, Hitz, 1982) leading to changes in some metabolic pathways, including sugar metabolism, accumulation of sugars and many organic compounds (Iljin, 1957; Kameli, Löselδ, 1993). Most of plants increase their sugar content under water stress (Kameli, Löselδ, 1993; Vassiliev, 1936), which is inconsistent with the results of this study. Possibly the sugar content increase in TKS roots occurs at the initial stage of water stress, while sugar redistribution between TKS aboveground and belowground parts was in favor of the latter, and the force of water stress in the current study was not strong enough to increase sugar concentration in TKS roots.

When the soil water content was less than 22.8%, the rubber content decreased significantly, and at values above 28.0%, the rubber content did not change. This suggests that only a certain intensity of water stress causes a decrease in the rubber content (Miyamoto, Bucks, 1985; Hammond, Polhamus, 1965; Bucks et al., 1985; Allen et al., 1987). Veatch-Blohm et al. (2006) found that rubber content in guayule biomass increased under the influence of water stress, since the guayule biomass decrease was corresponded to the increase of rubber content. The results of the current study may be related to the fact that TKS rubber amount decreased more than the amount of TKS biomass against the background of reduced irrigation; in addition, lower soil moisture reduces the TKS nutrient uptake, which leads to a decrease in TKS rubber content. M. Arias et al. (2016) found the TKS rubber content to be about 1.4%, which is very different from our data (about 5.0%).

In the current study, with a decreasing watering frequency, the TKS leaves and roots biomass gradually decreased. Since the TKS root number did not change, while the TKS root length decreased, it is obvious that the decrease in the root biomass was due to a decrease in the TKS root length. The increasing ratio of TKS root to TKS leaf biomass indicates that under conditions of reduced watering frequency, there is an increase in TKS underground biomass, which is due to the fact that an increase in the number of root hairs is required for nutrient uptake for alleviating soil water stress, which is consistent with previous studies. Roots, stems and leaves are systems that maintain the dynamic balance, reflecting the activity of aboveground and underground resources (light and CO_2, water and nutrients) (Poorter et al., 2012). The difference in the root/leaf ratio between treatments 1 and 2 was not significant, probably due to limited soil nutrients that could not support TKS to release more biomass.

This study provides only preliminary understanding of the effect of water stress on the TKS growth and yield. The present study confirms the prospects of the effect of water stress on the yield of TKS (Poorter et al., 2012).

Conclusion

The results of the study showed the trends in the irrigation frequency effect on TKS yield parameters. An increase in soil moisture (irrigation frequency indicator) from 22.8 to 38.9% caused the increases in TKS leaf biomass from 19.5 to 104.1 g/plant, TKS root biomass from 4.1 to 11 g/plant, and TKS rubber yield from 197.6 to 563.6 g/plant. Sugar yield varied from 100.4 to 264.9 g/plant.

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Information about the authors

Guang Shen, PhD, Institute of Natural Resources and Ecology, Heilongjiang Academy of Sciences, No. 103, Haping Road, Xiangfang District, Harbin, Heilongjiang Province, China, shen19772@163.com, https://orcid.org/0000-0001-5320-6465

Fuyun Zheng, Master, Institute of Natural Resources and Ecology, Heilongjiang Academy of Sciences, No. 103, Haping Road, Xiangfang District, Harbin, Heilongjiang Province, China, zhengfuyun@163.com, https://orcid.org/0000-0002-8966-5230

Lin Zhou, Master, Associate Researcher, Institute of Natural Resources and Ecology, Heilongjiang Academy of Sciences, No. 103, Haping Road, Xiangfang District, Harbin, Heilongjiang Province, China, 1016393991@qq.com, https://orcid.org 0000-0002-9695-417X

Xiangjun Zeng, Bachelor, Department of Science and Technology, Heilongjiang Academy of Sciences, Harbin: No. 204, Zhongshan Street, Nangang District, Harbin, Heilongjiang Province, China, xiangjunzeng@126.com, https://orcid.org/0000-0002-2042-9969

Nina G. Konkova, Researcher, N.I. Vavilov All-Russian Institute of Plant Genetic Resources, 42, 44 Bolshaya Morskaya Street, St. Petersburg 190000, Russia, n.konkova@vir.nw.ru, https://orcid. org/0000- 0002-4920-3904

Информация об авторах

Гуан Шень, доктор философии, Институт природных ресурсов и экологии Академии наук провинции Хэйлунцзян, Китай, провинция Хэйлунцзян, Харбин, район Сянфан, ул. Хапин, № 103, shen19772@163.com, https://orcid.org/0000-0001-5320-6465

Фуюнь Чжэн, магистр, Институт природных ресурсов и экологии Академии наук провинции Хэйлунцзян, Китай, провинция Хэйлунцзян, Харбин, район Сянфан, ул. Хапин, № 103, zhengfuyun@163.com, https://orcid.org/0000-0002-8966-5230

Линь Чжоу, магистр, младший научный сотрудник, Институт природных ресурсов и экологии Академии наук провинции Хэйлунцзян, Китай, провинция Хэйлунцзян, Харбин, район Сянфан, ул. Хапин, № 103, 1016393991@qq.com, https://orcid.org 0000-0002-9695-417X

Сянцзюнь Цзэн, бакалавр, Департамент науки и техники, Академия наук провинции Хэйлунцзян, Китай, провинция Хэйлунцзян, Харбин, район Наньган, ул. Чжуншань, № 204, xiangjunzeng@126.com, https://orcid.org/0000-0002-2042-9969

Нина Григорьевна Конькова, научный сотрудник, Федеральный исследовательский центр Всероссийский институт генетических ресурсов растений имени Н.И. Вавилова, 190000 Россия, Санкт-Петербург, ул. Б. Морская, 42, 44, n.konkova@vir.nw.ru, https://orcid.org/0000-0002-4920-3904

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